Reflectance from a Sinusoidal Bottom and Discrimination of Water Types with Hyperspectral Data

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LONG-TERM GOALS

The availability of hyperspectral imagery raises the possibility of expanding the range and specificity of components that might be identified, and of delineating simple vertical structure. This is particularly important in the coastal zone where terrigenous sources of chromophoric dissolved organic material (CDOM) and inorganic particulates seriously complicate the retrieval of information from remote signals. Our long-term goal is the development of a set of spectral analysis tools that fully exploit the information content in hyperspectral image data, particularly as it applies to remote sensing of ocean color and the extraction of bathymetry, water quality and bottom type information.

OBJECTIVES

The present work addresses two issues that affect hyperspectral data analysis: the effects of morphology on bottom reflectance and the inversion of water-leaving radiance spectra to infer information about the the optical properties of the water.

The objective for the first task is to develop a model that portrays the reflectance of an irregular bottom. We assume that the bottom is locally Lambertian and characterize the irregularity using a sine wave of varying amplitude and wavelength. The assumption of local Lambertian reflectance does not imply that the overall reflectance is Lambertian since in the far-field, inhomogeneities, texture, variations in slope and large-scale roughness become important in determining the reflectance distribution. The fundamental question is the degree to which bottom morphology will alter the magnitude and spectral quality of the light reflected from the bottom.

The second objective is to make better use of the full spectral range available in hyperspectral data to relate the water leaving radiance to the water IOPs. In particular, we will examine spectral derivative relationships (higher order derivatives, ratios of derivatives, etc.) for insights into the design of more effective hyperspectral ocean color algorithms.

APPROACH

1) In modeling bottom reflectance we use an analytical model in order to more easily and efficiently manipulate the illumination and viewing characteristics to better understand the reflectance process. All computations include 2^{nd} order reflectance since its contribution is expected to increase as the bottom slopes increase. The model is structured to be capable of including higher order reflectance,

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14. ABSTRACT

The availability of hyperspectral imagery raises the possibility of expanding the range and specificity of components that might be identified, and of delineating simple vertical structure. This is particularly important in the coastal zone where terrigenous sources of chromophoric dissolved organic material (CDOM) and inorganic particulates seriously complicate the retrieval of information from remote signals. Our long-term goal is the development of a set of spectral analysis tools that fully exploit the information content in hyperspectral image data, particularly as it applies to remote sensing of ocean color and the extraction of bathymetry, water quality and bottom type information.

15. SUBJECT TERMS

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but this may be impractical for an analytical approach. The model is designed to include shadowing and obscuration effects. Shadowing occurs when portions of the bottom are not directly illuminated and obscuration describes situations in which portions of the bottom are blocked from view by the detector by other bottom segments.

2) The premise of the second task is that we will generally have only the spectral water-leaving radiance to work with, and that any detailed information about the water and its constituents will be acquired through spectral decomposition of this signal. The analysis will be more effective if it is guided by an effective model. In this case a simple two-flow model (Philpot, 1987).

The key to identifying different water types lies in the relationship between the water irradiance reflectance, R_w, and water IOPs. The standard analytic model used for this purpose was originally derived by Gordon et al. (1975) and further developed in Gordon et al. (1988). The relationship most commonly used is of the form:

$$R_w \propto [b_b/(a + b_b)] \tag{1}$$

where a is the absorption coefficient and b_b is the backscattering coefficient. Equation (1) has been the basis for most of the semi-analytic algorithms designed to detect the presence and amount of chlorophyll in the water (O'Reilly et al., 1998; Reynolds et al., 2001). The most frequently used algorithms are based on spectral ratios. We are exploiting other possibilities, particularly the utility of derivative analysis. Our hypothesis is that it will be possible to relate the local spectral shape to changes in the water IOPs.

Taking the derivative of Equation (1) with respect to wavelength, λ, yields:

$$\frac{dR}{d\lambda} \propto \frac{1}{(a+b_b)^2}\left\{a\frac{db_b}{d\lambda} - b_b\frac{da}{d\lambda}\right\} \tag{2}$$

Equation (2) implies that the spectral changes in reflectance should be sharply different for turbid coastal waters as compared to clear ocean waters. In clear ocean waters, $a >> b_b$ and $db_b/d\lambda$ will be dominated by molecular scattering making the first term dominant except in the vicinity of a strong absorption peak (e.g., chlorophyll). In contrast, in a strongly scattering medium, the absorption coefficient will still be greater than b_b, but scattering will be dominated by particle scattering in which case one might expect little spectral variation in the scattering ($db_b/d\lambda \approx 0$). In that case, the second term will tend to dominate. This suggests, paradoxically, that the shape of the absorption spectrum can dominate the spectral change in reflectance for strongly scattering waters.

In summary, the approach is to examine this and other derivative relationships (higher order derivatives, ratios of derivatives, etc.) for insights into the design of more effective hyperspectral ocean color algorithms. The relationships will be tested using HYDROLIGHT (Mobley, 1995) to predict water-leaving radiance for ranges of water properties, supplemented by realistic IOPs computed using the Ocean Optical Plankton Simulator (OOPS) (Kim and Philpot, 2000). The relationships will be verified using existing field observations wherever possible.

WORK COMPLETED

1) The first version of an analytical model describing 1st and 2nd order reflections for a sinusoidal bottom has been completed and used to produce some preliminary results.

2) Derivative formulae have been derived based on the reflectance function in Equation (1).

3) Two study sites have been selected for exploring the modeled relationships: 1) the Atlantic Ocean off the coast of New Jersey, and 2) the Gulf Coast of Florida. Characteristic values for the range of pigments, CDOM, and particulates are being collected from the literature and available databases (e.g., the Worldwide Ocean Optics Database

RESULTS

The effect of bottom morphology on reflectance

The first case examined is that of a sandy, sinusoidal bottom. For simplicity, we allow the incidence angle to vary from +50° to -50°, but consider only a nadir-viewing detector for all cases. The maximum reflectance occurs for the sun at zenith and drops off rapidly as the sun angle increases (*Figure 1*). For a flat bottom there are virtually no 2nd order reflections. As the amplitude of the bottom waveform increases the reflectance remains symmetric with the illumination angle, and the amplitude of the first order reflectance decreases. The decrease is noticeable even for relatively modest amplitudes and the reflectance is down by almost 20% for the most extreme amplitude considered. However the contribution from the 2nd order reflections increases with the amplitude of the bottom waveform. This contribution is negligible for small amplitude waves but increases to about more than 10% of the total for the roughest waveform considered. Thus, the second order reflectance mitigates the change in the overall reflectance as the waveform amplitude increases.

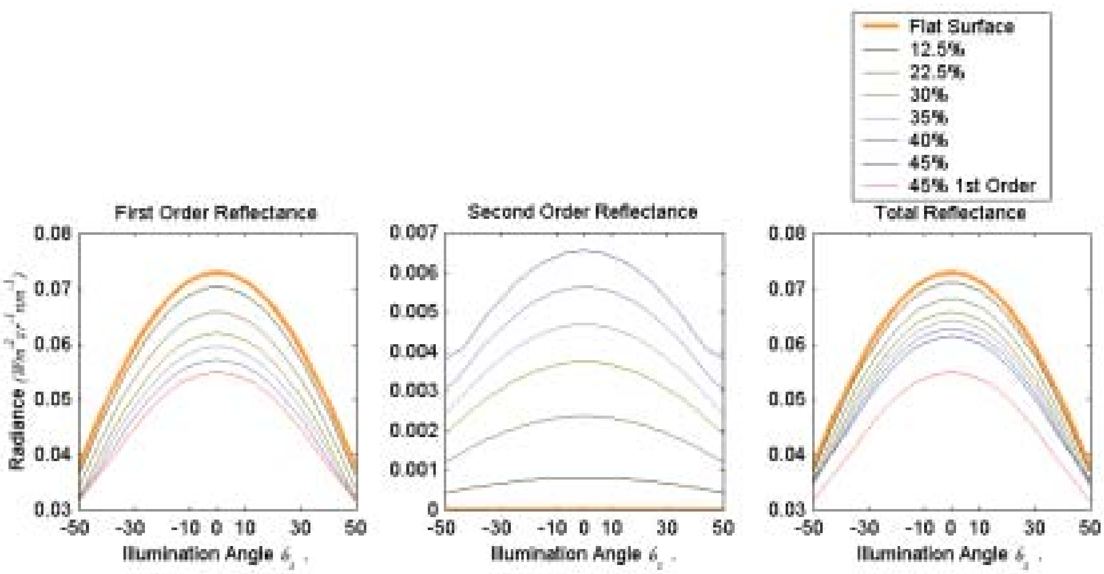

Figure 1. First and second order reflectances received by a nadir-viewing detector as wave amplitude changes and incidence angle varies.

a. First order reflectance decreases as the amplitude of the bottom waveform increases, falling by roughly 20% for the most extreme case.

b. Second order reflectance increases with the amplitude of the bottom waveform.

c. The decrease in the total reflectance is mitigated by the contribution of the second order reflectance. For the most extreme case the first order reflectance is shown as well as the total reflectance.

While the overall total reflectance is dominated by the magnitude of the first order reflections, the second order reflections make a significant contribution when the surface is very rough. For still more extreme waveforms the second order reflectance would even be more significant since second order reflectance would be the only radiation received from the shadowed and obscured regions of the waveform. Note that, for the wave amplitudes and illumination angles considered here, shadowing and obscuration effects are negligible. When these factors become more important the contribution of second order reflectance should increase substantially.

Shadowing of points along the bottom occur when the incidence angle is greater than the maximum slope of the waveform – in this case for waveforms with amplitude-to-length ratios above 25%. Similarly, obscured points are those that do not have direct paths to the detector, but which have not been considered in this simplifying case of nadir viewing. The drop in first order reflectance is expected to be greater for when shadowing occurs than that for obscuration. On the other hand, there is much greater contribution from second order reflections to total reflectance in regions that are shadowed. It is interesting to note though that this does not affect the symmetry of the total reflectance of a single waveform as the illumination angle changes.

IMPACT/APPLICATIONS

Bottom reflection: While the overall total reflectance is dominated by the magnitude of the first order reflections, the second order reflections make a significant contribution when the surface is very rough. For still more extreme waveforms the second order reflectance would be even more significant since second order reflectance would be the only radiation received from the shadowed and obscured regions of the waveform. Note that, for the wave amplitudes and illumination angles considered here, shadowing and obscuration effects are negligible. When these factors become more important the contribution of second order reflectance should increase substantially.

TRANSITIONS

None

RELATED PROJECTS

The bottom reflectance portion of this project is part of a collaborative and cooperative effort to explore the character of reflectance from a sea bottom that is not flat. We will coordinate with Drs. Zaneveld and Boss, who are approaching the problem using ray tracing and Monte Carlo models for similar conditions. Each model has its own strengths and weaknesses, but the models should match under appropriate conditions. The intent is to use each model where it is strongest, crosschecking the models where feasible and, as a group, developing a consistent description of the effect of morphology on the spectral and directional reflectance of the sea bottom. (Zaneveld & Boss, submitted)

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PUBLICATIONS

Clavano, W.R. and W. D Philpot (2002) *Reflection from a sinusoidal surface.* Ocean Optics XVI, 18-22 November, 2002, Santa Fe, NM.